Communication of Tomorrow via Satellites*

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WHY should an engineer be interested in space? As a challenge, of course. The problem of building a spaceship seems good for endless decades and billions of dollars if the Government continues in its present frame of mind. And, with a spaceship, one might visit the moon, and Mars, and find—who knows what?

Whatever a space traveller may find on Mars is unlikely to be as interesting, as complicated, or as puzzling as any of the three thousand million private universes which constitute Earth's mankind. Most of the 180 million of these who live in the United States can be reached faster than any spaceship could travel, by means of the seventy million telephones in North America.

There are fewer than this number of telephones in all the rest of the world. The number is growing, however, and we may expect it to grow greatly. Ninety-four per cent. of the world's people live beyond the seas. The problem of establishing adequate communication with them is as challenging, if not as difficult, as that of journeying to Mars, and it seems much more important to mankind.

If one draws a line north and south across the United States it will cut across two-way communication channels having a total bandwidth of around 100 megacycles. This is a bandwidth equal to that of about 25 television signals or 25,000 voice signals. These communication channels are provided by microwave systems with many successive line-of-sight links from tower to tower, each link around 30 miles long, and by cable pairs and coaxial cables with amplifiers spaced sometimes closer than 4 miles.

Except for a tropospheric scatter link from Florida to Cuba, there are no television circuits across the oceans. Transoceanic telephone circuits are provided by short-wave radio, which is subject to fading and is sometimes interrupted entirely, and by telephone cables to Scotland, France, Hawaii, Puerto Rico, Cuba and Alaska. All of these facilities total a bandwidth of around a megacycle, about one-hundredth that of the circuits which cross the United States. On these few circuits we must rely for electrical communication with 94% of the world's people.

Radio waves travel in straight lines. Waves of lower frequencies are bent around the horizon by the ionosphere, but microwaves, which provide so much of our continental communication, go straight into space. To communicate across the ocean by means of microwaves one would need a relay visible from both sides of the ocean at the same time. A satellite might provide the site for such a relay.

This idea occurred to Arthur C. Clarke, science and science-fiction author and physicist, in 1945. He published a paper on it in the *Wireless World.* The idea so intrigued me that in 1954 I wrote a paper which was published in *Jet Propulsion* the following year. How much different things look now, though, for there are actually satellites in the sky!

One of these, the first Vanguard satellite, is equipped with a transistor radio transmitter powered by solar cells. It is still sending out radio signals more than two years since its launching. This is certainly encouraging. Experience with more complicated satellites is a little less encouraging, however. The signals from Explorer VI died out after about two months, and the storage batteries aboard Pioneer V showed signs of weakening after a like period. One can gather scientific data by means of electronic equipment with such a lifetime expectancy, but one can scarcely use such equipment to keep in touch with the world over a period of years, and especially when it costs several million dollars to launch a satellite.

One possibility is to use a satellite with no radio equipment aboard. The Echo project of N.A.S.A. (the National Aeronautics and Space Administration) contemplates just this. A 100-foot diameter, 130-pound balloon satellite made of aluminized Mylar (Melinex), 0·0005 in. thick, is to be put in a 1,000-mile high orbit. Fig. 1 shows this 10-storey balloon. A transmitter at the Bell Telephone Laboratories' Holmdel location will beam 960-megacycle signals at it. A part of the signal reflected by the

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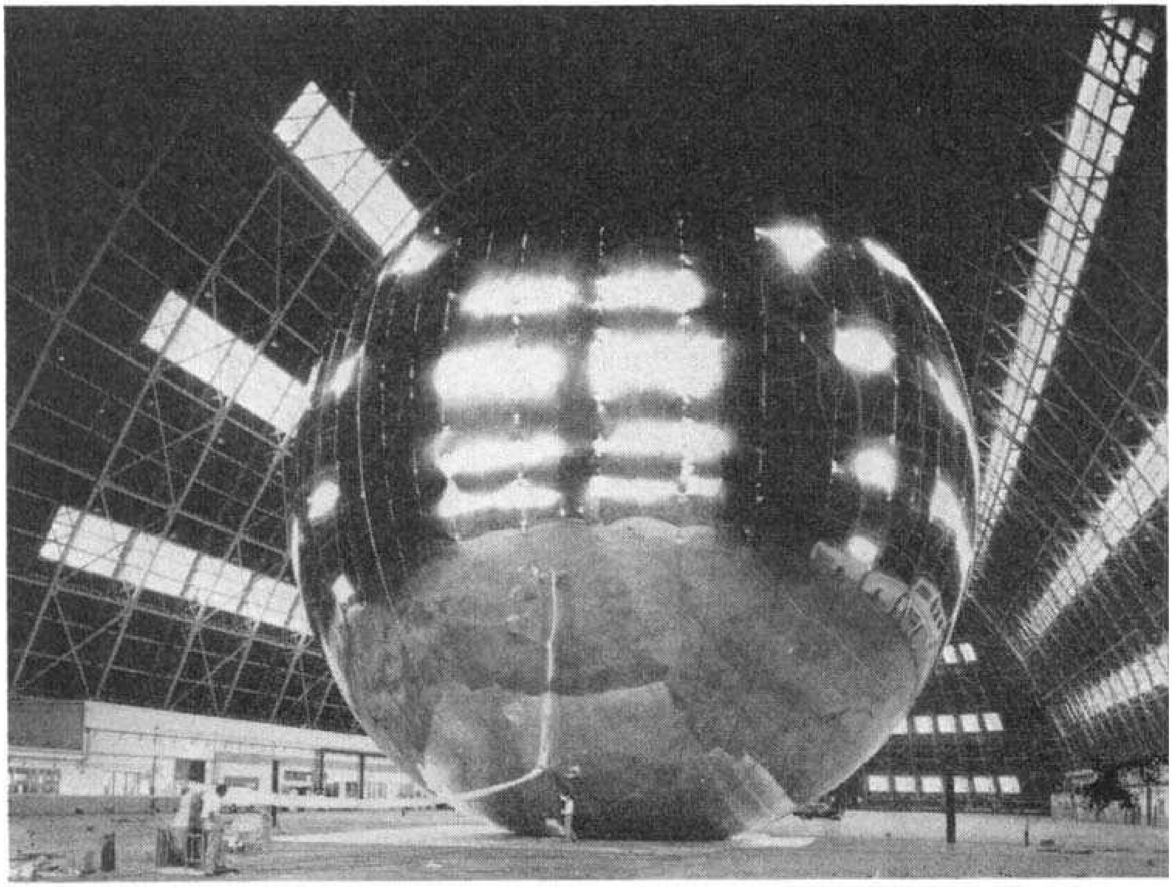
satellite will be received at the Jet Propulsion Laboratory's Goldstone station in California. In turn, Goldstone will use the satellite to transmit 2,390 megacycle signals to Holmdel. The intent of this experiment is to establish a two-way telephone circuit across the country via satellite for some 15 minutes at a time, to measure radio propagation over the path, to determine the life of the balloon in orbit, and generally to get experience with the problems of satellite communication.

Even a 100-ft. balloon reflects only a very faint signal back to earth when it is a thousand miles high. To make use of the faint signal received at Holmdel, a maser receiver, which operates at liquid helium temperature, is used. If such a receiver were connected to an ordinary parabolic dish antenna, the microwave noise received from the hot (room temperature) earth by the side and back lobes of the antenna would render it ineffective. For this reason the special horn-reflector antenna shown at the right of Fig. 2 is used. This receives almost no radiation from the back and side directions. In fact, the total noise of the receiver consisting of the maser and the horn-reflector antenna is equivalent to the microwave energy radiated by an object less than 20 centigrade degrees above absolute zero.



The 100-ft. diameter plastic-film satellite during an inflation test at Langley Field, Virginia. The film is vacuum-coated with aluminium

The problems are formidable. Fig. 2 shows the satellite communication equipment at Holmdel.

The problem of tracking the Echo satellite to an accuracy of 1/10 degree is no small one. Radar observations will be sent to N.A.S.A. Goddard Space Flight Centre in Washington, D.C., by teletypewriter. There the satellite orbit will be computed. Further, the angle at which the Holmdel and Goldstone antennas should point every two seconds, and the rates at which they should be slewing, will be computed. These data, together with the corresponding times, will be received at Holmdel and Goldstone via teletypewriter as punched tape. This tape can then be fed into digital-analogue converters to drive the antennas. This tracking scheme has already been used successfully in Tiros, which reflected faint but measurable signals to Goldstone from Holmdel.

Even with 10 kilowatts transmitter power and so sensitive a receiver, communication is difficult. Frequency modulation helps to improve the signal-to-noise ratio, but ordinary f.m. receivers accept the noise over a broad bandwidth. For this reason a special "f.m. with feedback" receiver is used. In this receiver the local oscillator tracks the received signal in frequency, so that the frequency deviation of ± 30 kc/s is used, and yet the i.f. bandwidth is only 6 kc/s. By this means a 20 dB signal-to-noise advantage is obtained.

An attempt to launch an Echo satellite on 13th

May, 1960, failed. I hope that a satellite will be in orbit as you are reading this article. At its writing several Echo balloons have been lofted 200 miles from Wallop's Island, Virginia, by means of solid-fuel rockets in "Shot Put" tests. Voice signals were successfully transmitted from Holmdel to a Lincoln Laboratory's receiver at Round Hill, Massachusetts, by means of the third Shot Put balloon.

If the Echo balloons have a sufficiently long life, transoceanic telephone and television by means of such balloons will be technically feasible. Thirty balloon satellites randomly spaced in polar orbits about 3,000 miles high could provide almost continuous transatlantic service, and could be used for other transoceanic communication as well. Powers of tens of kilowatts would be required with antennas more than 100 ft. in diameter.

Active satellites in such low orbits would reduce the required transmitted power and antenna size. To be useful, an active satellite would have to have a long, trouble-free life; there are no repairmen in space. A low power, about one watt, would be sufficient, and the use of a low power seems necessary for long life. Further, one can't afford to radiate much power from space; it could interfere with ground microwave circuits.

Another possibility is to use satellites in equatorial orbits 22,300 miles above the surface of the earth. Such satellites would stand still with respect to the surface of the rotating earth, and any one satellite would be visible over more than one-third of the globe. Directive antennas would be needed on the satellite, and so some mechanical and electronic gear would have to be used to keep the antennas pointed at the earth. Other apparatus would be needed to keep the satellite in a fixed place in the sky, despite perturbations of the orbit. All this orientation and station-keeping gear, as well as the radio equipment, would have to have a long life. Such long-life equipment does not exist at present. Further, tests have shown that the amount of transmission time to and from the satellite can have an annoying effect on telephone conversations, though this may not be a fatal defect.

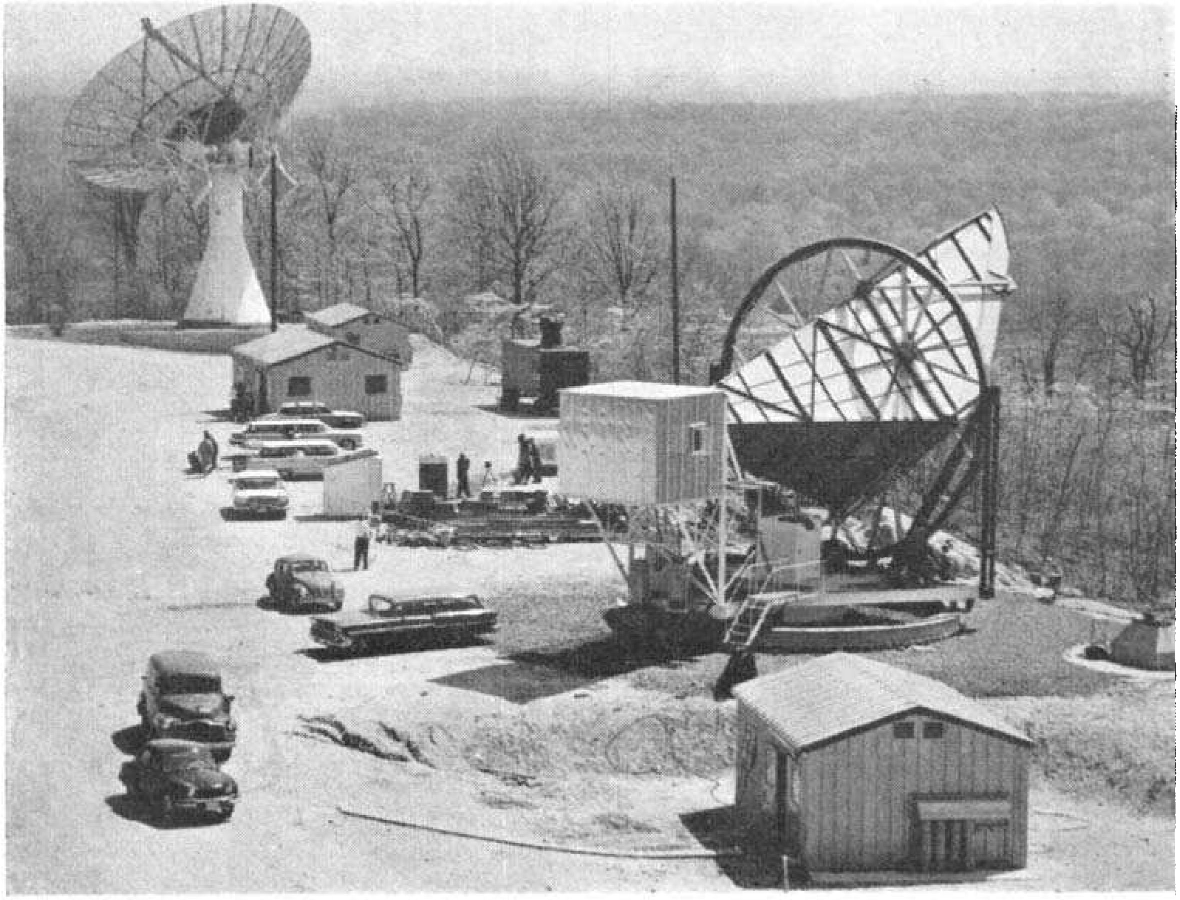


Fig. 2. The aerial site near the Bell Telephone Laboratories at Holmdel, New Jersey. The parabolic reflector of the 960-Mc/s transmitter is to the left, while the horn-reflector, with maser low-noise amplifier, is mounted on the turntable in the foreground

We do not even have very accurate knowledge of how the radiation which could damage solar batteries in satellites varies with time. Satellite communication exasperates an engineer by its many unknowns and undones, which are coupled with a very real promise.

Research on both passive and active satellite systems may help to make transoceanic satellite communication practical. The job is a big one, however. No one knows how far in the future the effective, day-by-day use of satellites as a part of our world-wide communications may lie.